NITROGEN NUTRITION AND GROWTH
REGULATOR PROPERTIES OF OXAMIDE
ON WHEAT AND SOYBEAN

by

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Table of Contents

List of Tables.............................. i

Introduction................................ 1

Materials and Methods....................... 4

Results..................................... 8

Discussion..................................17

References..................................19

Abstract....................................1a

List of Tables

Table 1. Response of 'Newton' wheat to foliar oxamide treatment at Hutchinson, Kansas and Manhattan, Kansas, 1983.................................. 9

Table 2. Mean response of 'Newton' and 'Eagle' wheats to foliar oxamide at Hutchinson, Kansas and Manhattan, Kansas, 1984....................... 10

Table 3. Response of 'Crawford' soybean to soil and and foliar application of oxamide at Manhattan, Kansas, 1985............................. 12

Table 4. Response of 'Len' wheat to oxamide supplied via the roots in hydroponic culture........... 13

Table 5. Response of 'Crawford' soybean to oxamide supplied via the roots in hydroponic culture..... 15

INTRODUCTION

Slow-release nitrogen fertilizers promote efficient use of applied N by reducing losses from leaching, fixation, or decomposition. Nitrogen is ideally released in amounts sufficient for optimum plant growth while avoiding excessive soluble N in the soil[15,16,20]. High production costs per unit of N, however, usually restrict use of slow-release N compounds to ornamentals and turfgrasses.

Oxamide, the diamide of oxalic acid, has potential as a slow-release N fertilizer[22]. The compound contains 31.8% N and is 0.4% soluble in water at 25°C; dissolution rate, however, is an inverse function of particle size and hardness[7]. Hydrolysis in water produces oxamic acid in equilibrium with the constituent acid and base, whereas hydrolysis in soil is thought to occur mostly through microbial activity and release of ammonium. Once dissolved, N from oxamide undergoes rapid ammonification and nitrification.

Nitrogen from oxamide was as available as ammonium nitrate to corn (Zea mays L.) in greenhouse studies[8]. In field studies, a sorghum-sudan hybrid (Sorghum bicolor) took up more N from urea than from oxamide early in the growing season. Uptake of N from oxamide was greater during the latter part of the season, however, and total seasonal N uptake was similar for both sources[28]. Total dry matter yields of annual ryegrass were also similar whether N was supplied as oxamide, urea, or ammonium nitrate[6]. Seasonal

distribution of dry matter was somewhat more favorable with oxamide. Nitrogen from finely ground oxamide was also readily available to oats (Avena sativa L.), but uptake of N decreased as the particle size of oxamide increased[7].

Oxamide may function as a growth regulator as well as a nitrogen source for plants. Recent reports indicate that it may have ethyleneinhibiting properties. Aqueous solutions of oxamide inhibited ethylene production in orange peel discs and also blocked ethylene production and delayed abscission when applied to orange fruits[24].

Ethylene is produced by plant tissues in response to stress, wounding, and hormonal stimulii[11]. It also promotes senescence of plant tissue, ripening of fruits, and abscission of leaves, flowers, and fruits[19]. Although its mode of action is uncertain, oxamide might block ethylene activity by promoting production of polyamines within plants or by action as a polyamine itself (B.E. Rehberg, personal communication). Polyamines counter the effects of ethylene-promoted senescence in plant tissue[2,4,5].

The growth regulator properties of oxamide suggest that plant responses may differ between soil and foliar applications of the compounds. Whereas oxamide applied to soil is rapidly degraded[7,22], oxamide applied to foliage may function as both a growth regulator and plant nutrient. The present studies determined effects of oxamide applied to the foliage of wheat (Triticum aestivum L.) and compared effects of

foliar and soil applications on soybean (*Glycine max* L. Merr.). Utilization of oxamide by wheat and soybean grown in hydroponic culture, in which microbial activity is less than in soil, was also determined.

MATERIALS AND METHODS

Field studies were conducted during the 1983 and 1984 wheat crop seasons at Manhattan and Hutchinson, Kansas. The soils were Ivan and Kennebec silt loams (fine-silty, mixed, mesic Cumulic Hapudolls) at Manhattan and Clark-Ost complex (fine-loam, mixed, thermic Typic Calciustolls and Argiustolls) at Hutchinson. The soil analyses were pH 6.6, 14 $kg \cdot ha^{-1}$ available N, 19 $kg \cdot ha^{-1}$ available P, and 379 $kg \cdot ha^{-1}$ exchangeable K at Manhattan, and pH 7.1, 16 $kg \cdot ha^{-1}$ available N, 22 $kg \cdot ha^{-1}$ available P, and 470 $kg \cdot ha^{-1}$ exchangeable K at Hutchinson.

'Newton', a semidwarf hard red winter wheat, was established in randomized complete block designs with four replications at Manhattan 1 October 1982 and at Hutchinson 7 October 1982. The seeding rate was 84 $kg \cdot ha^{-1}$ (approximately 250 $seeds \cdot m^{-2}$) in plots containing six rows 20 cm apart and 10 m long. All plots received 24 $kg \cdot ha^{-1}$ P as superphosphate fertilizer before planting and 101 $kg \cdot ha^{-1}$ N as ammonium nitrate after planting.

Experimental treatments were applied at the early boot and early flowering stages (Feekes scale 10.2 and 10.5.1, respectively) at both locations. The treatments consisted of 67 $kg \cdot ha^{-1}$ urea N, 67 $kg \cdot ha^{-1}$ plus 3% (v/v) Vitavax fungicide, 50 $kg \cdot ha^{-1}$ urea N plus 17 $kg \cdot ha^{-1}$ oxamide N, 33.5 $kg \cdot ha^{-1}$ urea N plus 33.5 $kg \cdot ha^{-1}$ oxamide N, 17 $kg \cdot ha^{-1}$ urea N plus 50 $kg \cdot ha^{-1}$ oxamide N, and 67 $kg \cdot ha^{-1}$ oxamide N. The

total amount of each treatment was divided evenly between the two stages and applied in 374 $L\cdot ha^{-1}$ water each time; control plots received no foliar applications.

Duration of leaf viability was assessed by visually estimating the proportion of green leaves on a scale of 1 to 10. Severity of leaf rust infection was rated similarly during grain development, with 1 indicating no rust and 10 severe infection. Grain was harvested with a plot combine at maturity and test weight was measured by weighing a 0.45-L subsample, and protein was determined by infrared reflectance.

A second study in 1984 used Newton and 'Eagle', a tall, hard red winter wheat, as main plots and foliar treatments as subplots in a split plot design at the same locations. The wheats were planted at 100 $kg\cdot ha^{-1}$ at Manhattan 25 October 1983 and 84 $kg\cdot ha^{-1}$ at Hutchinson 17 November 1983. Fertilizer application and plot size were the same as the previous year. Urea and oxamide N rates also were the same as in 1983, but the total amount was applied at the flowering stage of wheat. Grain was harvested and yield, test weight, and protein were determined as before.

Soybean studies used 'Crawford', an indeterminant cultivar, planted at Manhattan 26 June 1985 in the Ivan-Kennebec silt loam described above. Each plot contained four rows 76 cm apart and 10 m long with seeds spaced 3.81 cm in the rows. Treatments were in a split plot design, with

foliar vs. no foliar applications of oxamide as whole plot treatments and four soil-applied rates of IBDU (isobutylidene diurea) or oxamide as subplot treatments in four replications. Oxamide was applied as a 10^{-2} $\underline{M}$ solution with 0.1% (v/v) triton on whole plots to foliage of soybean at early flowering (R1), mid-flowering (R2), and early pod (R3) stages. IBDU and oxamide were applied at rates of 0, 11, 22, and 33 $kg \cdot ha^{-1}$ N and worked into the soil at the V5 stage of soybean.

Shoots from two 0.5-m-long sections of each plot were cut at ground level at physiological maturity, dried five days at $40^{o}C$, and weighed. The pods on each plant were counted and the plant samples were ground through a Christy mill followed by a Udy Cyclone mill with a 1-mm sieve. The balance of the soybean plots was harvested 31 October 1985, and yield, moisture content, test weight, and 100-bean weight were measured. A subsample of beans from each plot was frozen and ground through the Udy mill with a 1-mm sieve. Nitrogen concentration of the whole plot samples and beans was determined by the micro-Kjeldahl method.

Hydroponic studies to observe responses of plants to oxamide supplied to roots used Crawford soybean and 'Len', a semidwarf spring wheat. Seeds were germinated in vermiculite and 2-week-old seedlings were transplanted to 2-L opaque polystyrene pots each holding four plants. Plants received a complete Hoagland nutrient solution for two weeks and then

were supplied a modified solution in which $Ca(NO_3)_2$ and KNO_3 were replaced by equimolar amounts of $CaCl_2$ and KCl, respectively. Nitrogen was present as 15 m*M* N from $NaNO_3$ (control), oxamide or IBDU; 7.5 m*M* $NaNO_3$ plus 7.5 m*M* oxamide or IBDU; 7.5 m*M* $NaNO_3$; and 7.5 m*M* N as oxamide.

Soybean plants were grown to maturity in a glasshouse with natural lighting (fall of 1985) and mean temperatures of 30°C during the day and 20°C during the night. The wheat was grown in an environmental chamber having 16-hr days with 320 umol m^{-2} s^{-1} PAR at 26°C and 8-hr nights at 20°C. For both species, nutrient solutions were adjusted to 2-L volume with distilled water and to pH 5.8 for soybeans and pH 4.5 for wheat bi-daily. The solutions received supplemental Fe semiweekly and were replaced weekly. Plants were harvested at maturity, dried at 60°C, and threshed. Yield components were calculated and vegetation and grain were ground separately and analyzed for nitrogen concentration as described above.

Data were analyzed statistically by standard analysis of variance procedures using the SAS computer package.

RESULTS

Foliar spraying failed to increase yield or test weight of Newton in either year. The 1984 results indicated no cultivar by treatment interaction when both Newton and Eagle were given the foliar sprays. Protein concentration of the grain was increased by the foliar treatments in both years. In the 1983 study, plots at Hutchinson receiving only urea had higher grain protein than those receiving urea and oxamide in combination, with the amount of increase diminishing as the proportion of oxamide in the spray increased (Table 1). Grain protein concentrations at Manhattan increased over the control by similar magnitudes for all treatments.

Table 2 shows the results of the 1984 wheat study. Since no significant cultivar by treatment interaction was found, the values are the means over both cultivars. The response of grain protein to the foliar sprays at Hutchinson followed the same trend as the previous year. Grain protein was not increased significantly at Manhattan, however, when the foliar spray contained less than 50% of its N as urea. Test weight was reduced for the Manhattan plots receiving the urea spray, although grain from plots receiving the same concentration of urea but with Vitavax did not decrease in test weight.

Response of Crawford soybean indicated no significant spray treatment effect or any apparent spray treatment by

TABLE 1

Response of 'Newton' wheat to foliar oxamide at Hutchinson, Kansas and Manhattan, Kansas, 1983.[1]

Treatment		Grain yield		Test weight		Grain protein	
Urea	Oxamide	Hutch	Man	Hutch	Man	Hutch	Man
---$kg \cdot ha^{-1}$ N---		----$kg \cdot ha^{-1}$---		--$kg \cdot m^{3-1}$-		----$gm \cdot kg^{-1}$----	
67.00	0	2093 a	1657 a	768 a	616 b	132 ab	161 a
50.25	16.75	2374 a	1602 a	765 a	643 a	132 a	157 ab
33.50	33.50	2238 a	1672 a	769 a	643 a	129 abc	156 b
16.75	50.25	2277 a	1800 a	769 a	654 a	128 bc	150 c
0	67.00	2379 a	1763 a	768 a	649 a	123 d	147 c
67.00 + Vitavax		2212 a	1498 a	773 a	642 a	127 c	159 ab
0	0	2078 a	1638 a	767 a	650 a	110 e	147 c
CV (%)		13.2	18.2	1.3	2.0	2.5	2.2

[1]Values in columns followed by different letters differ significantly at $p=0.05$ according to Duncan's Multiple Range Test.

TABLE 2

Mean response of 'Newton' and 'Eagle' wheats to foliar oxamide at Hutchinson, Kansas and Manhattan, Kansas, 1984.[1]

Treatment		Grain yield		Test weight		Grain protein	
Urea	Oxamide	Hutch	Man	Hutch	Man	Hutch	Man
--kg·ha^{-1} N---		---kg·ha^{-1}---		--kg·m$^{3-1}$--		---gm·kg^{-1}---	
67.00	0	2750 a	5058 a	908 a	960 a	101 a	91 a
50.25	16.75	2590 a	5678 a	942 a	970 a	96 b	94 a
33.50	33.50	2681 a	5303 a	935 a	975 a	92 c	89 a
16.75	50.25	2718 a	5765 a	942 a	960 a	90 c	88 a
0	67.00	2922 a	5387 a	945 a	960 a	87 d	88 a
67.00 + Vitavax		2698 a	4612 a	942 a	958 a	101 a	90 a
0	0	2720 a	5258 a	912 a	942 a	81 e	63 b
CV(%)		12.1	15.4	3.7	2.7	2.4	16.8

[1]Values in columns followed by different letters differ significantly at p=0.05 according to Duncan's Multiple Range Test.

soil treatment interaction for any component measured (Table 3). Hence, results are the means over both spray treatments for each soil treatment.

Test weight tended to increase slightly with increasing N for both fertilizers. However, no increases or decreases in the other components measured were produced by any soil treatment, the spray treatment, or any combination of the two when compared to the control.

Results from the hydroponic study on Len wheat are given in Table 4. Responses of yield components measured did not differ among plants receiving either oxamide or IBDU alone at the highest concentration. Both treatments, however, gave much lower responses than nitrate at the highest rate, especially for yield, which was approximately seven times as great for the nitrate-fed plants. Feeding either oxamide or IBDU at the highest concentration generally resulted in less vegetative and root matter and fewer tillers and seeds as well as lower seed weight. While plants receiving nitrate and IBDU in combination generally performed as well as those receiving the high nitrate treatment, plants receiving the nitrate-oxamide combination were significantly poorer. Plants given nitrate only at the half-rate performed similarly to control plants given the full rate. Oxamide at the half-rate gave responses which, except for number of tillers and seeds produced, were significantly less than the control plants. Feeding oxamide instead of nitrate at the half-rate

TABLE 3

Response of 'Crawford' soybean to soil and foliar application of oxamide at Manhattan, Kansas, 1985.[1]

Treatment				Protein	
IBDU	Oxamide	Yield	Test wt.	Vegetation	Seed
--kg·ha^{-1} N--		kg·ha^{-1}	kg·m3-1	----gm·kg1----	
11.2	0	1723 a	752 c	158 a	389 a
22.4	0	1819 a	758 abc	150 a	390 a
33.6	0	1805 a	758 ab	160 a	389 a
0	11.2	1889 a	757 abc	161 a	381 a
0	22.4	1808 a	759 ab	156 a	378 a
0	33.6	1819 a	761 abc	155 a	387 a
0	0	1722 a	754 bc	161 a	382 a
CV (%)		9.7	0.7	8.0	3.9

Table 3 continued.

Treatment				
IBDU	Oxamide	Pod no.	Dry wt.	Bean wt.
--kg·ha^{-1} N--		plant^{-1}	g·plant^{-1}	g·100^{-1}
11.2	0	38.0 a	51.0 a	12.3 a
22.4	0	39.8 a	50.7 a	12.0 a
33.6	0	37.1 a	48.8 a	12.5 a
0	11.2	39.8 a	47.6 a	12.0 a
0	22.4	39.4 a	52.1 a	12.4 a
0	33.6	36.0 a	49.0 a	12.2 a
0	0	33.5 a	45.3 a	12.1 a
CV (%)		18.1	13.0	3.4

[1]Values in columns followed by different letters differ significantly at p=0.05 according to Duncan's Multiple Range Test.

TABLE 4

Response of 'Len' wheat to oxamide supplied via the roots in hydroponic culture.[1]

Treatment					Dry weight	
NO_3	Oxamide	IBDU	Yield	Spikes per plant	Vegetation	Root
------mM N------			$g \cdot plant^{-1}$	no.	$g \cdot plant^{-1}$	$g \cdot plant^{-1}$
15	0	0	6.4 a	5.8 a	7.1 a	1.3 a
0	15	0	0.8 d	2.7 d	2.8 d	0.4 c
0	0	15	0.9 d	3.4 cd	3.5 cd	0.4 c
7.5	7.5	0	2.6 c	4.0 bcd	3.5 cd	0.5 c
7.5	0	7.5	5.9 a	6.4 a	5.9 ab	0.7 b
7.5	0	0	5.5 ab	5.1 ab	5.8 ab	1.3 a
0	7.5	0	4.1 bc	5.0 abc	4.7 bc	0.4 c
CV (%)			30.6	22.0	19.9	21.8

Table 4 continued.

Treatment					Protein	
NO_3	Oxamide	IBDU	Seed weight	Seeds per plant	Grain	Vegetation
------mM N------			mg	no.	------$g \cdot kg^{-1}$------	
15	0	0	39.3 a	160 a	165 d	54 a
0	15	0	12.6 d	69 c	237 ab	53 a
0	0	15	12.5 d	70 c	267 a	49 ab
7.5	7.5	0	25.3 c	103 bc	233 bc	52 ab
7.5	0	7.5	35.4 ab	165 a	214 bc	48 ab
7.5	0	0	41.1 a	134 ab	166 d	46 ab
0	7.5	0	29.9 bc	133 ab	204 c	40 b
CV (%)			15.0	21.6	10.1	14.5

[1]Values in columns followed by different letters differ significantly at p=0.05 according to Duncan's Multiple Range Test.

resulted in less root material and smaller seed. Nitrate and oxamide in combination generally were not any better than oxamide alone at the half rate, though both treatments were better than oxamide alone at the full rate. Grain protein was lowest for plants receiving nitrate alone either at the full or half rates. Plants receiving N solely from oxamide or IBDU at the full rate contained the highest concentration of protein, with the IBDU plants containing the higher concentration of the two. Grain protein was inversely related to yield. The protein concentration of the vegetation differed only among three treatments, with plants receiving either nitrate or oxamide alone at the full rate having significantly higher protein concentrations than plants receiving oxamide alone at the half rate.

Soybean grown in hydroponic culture and given IBDU or oxamide at the full rate yielded approximately one-half that of plants given nitrate and either oxamide or IBDU in combination (Table 5). Plants given either oxamide or IBDU at the half rate, yielded similarly but only approximately one-half that of control plants. The two half-rate treatments supported yields that were similar to those of plants receiving the full rate of oxamide or IBDU, however.

Plants receiving oxamide or IBDU at the full rate generally did not respond as well as plants fed nitrate at the same rate. Plants given the nitrate-oxamide or nitrate--IBDU combinations equalled the control plants in seed yield,

TABLE 5

Response of 'Crawford' soybean to oxamide supplied via the roots in hydroponic culture.

Treatment					Dry weight	
NO_3	Oxamide	IBDU	Yield	Pods per plant	Vegetation	Roots
------mM N------			$g \cdot plant^{-1}$	$plant^{-1}$	$g \cdot plant^{-1}$	$g \cdot plant^{-1}$
15	0	0	13.4 a	31.7 a	27.6 a	9.9 a
0	15	0	7.0 b	16.0 d	11.0 d	2.8 d
0	0	15	7.0 b	18.5 d	12.1 d	2.5 d
7.5	7.5	0	12.9 a	28.4 b	21.6 b	7.8 b
7.5	0	7.5	13.2 a	27.7 b	22.2 b	7.3 b
7.5	0	0	7.4 b	21.8 c	18.1 c	7.1 b
0	7.5	0	6.1 b	16.9 d	11.4 d	4.3 c
CV (%)			8.3	8.1	7.5	9.9

Table 5 continued.

Treatment					Protein	
NO_3	Oxamide	IBDU	Seed weight	Beans per plant	Vegetation	Grain
------mM N------			mg	$plant^{-1}$	-----$g \cdot kg^{-1}$------	
15	0	0	186 a	73 a	16 e	337 d
0	15	0	199 a	35 c	75 b	403 b
0	0	15	211 a	33 c	106 a	458 a
7.5	7.5	0	193 a	67 a	37 c	351 bcd
7.5	0	7.5	201 a	66 a	23 de	392 bc
7.5	0	0	151 b	49 b	25 de	312 d
0	7.5	0	152 b	41 c	33 cd	350 bcd
CV (%)			8.9	11.0	16.5	9.3

[1]Values in columns followed by different letters differ significantly at p=0.05 according to Duncan's Multiple Range Test.

number of beans produced, and seed weight, but produced slightly fewer pods and less vegetation. Though they produced similar yields, plants receiving oxamide alone at the half rate produced fewer pods and less vegetation than did plants receiving nitrate at the half rate.

Root dry weight was greatest when plants were fed nitrate at the full rate and least when they received IBDU or oxamide at the full rate. The two N combinations supported slightly less root material than did the control. Plants given nitrate only at the half rate produced more root material than those receiving oxamide at the same rate and equalled that of plants given either of the combinations.

Protein concentration of the vegetation was highest for plants receiving IBDU or oxamide at the full rate. Plants given nitrate alone at the full or half rates contained the lowest concentration of protein. Grain protein was also highest when plants received IBDU at the full rate and, again, was inversely related to yield. Nitrate-fed plants contained the lowest grain protein concentrations and plants receiving the other treatments had protein concentrations intermediate to the two extremes.

DISCUSSION

Nitrogen sources such as urea applied to wheat foliage at flowering generally raise grain protein with little effect on yield[3,9,23]. Response of grain protein concentration to oxamide equalled the effect of urea at only one location in only one year. Protein was increased over the control in all but one instance, however, suggesting that entry of oxamide into the leaf was restricted.

Absorption of foliarly supplied substances is affected by various factors[21], including on leaf cuticle characteristics[10,17] and the physical structure of the applied compound[18] and its solubility[10,14]. While little is known about the uptake of oxamide thru the leaf, its low solubility likely played a role in its apparently restricted penetration.

Nitrogen fertilizer has resulted in increased yield of soybean[1,12,13], but responses are inconsistent and apparently dependent upon numerous environmental factors[25,26,27]. Nitrogen from the soil-applied oxamide and IBDU should have been released over a period of 50 to 60 days[6,7,8,22,28]. That no effect was observed may be due to the erratic response of nodulated soybeans to applied N in general.

Growth regulator responses of oxamide on wheat and soybean were not readily apparent. Effects of the compound on plant growth, development, yield, and chemical composition did not resemble those of ethylene inhibitors or polyamines observed in other studies[2,4,11,19,24]. Oxamide appeared to

function predominantly as a slow-release N source whether it was applied to the soil or foliage of plants in the field or to the roots of plants in hydroponic culture. Any physiological effects of oxamide other than as an N source, however, may have been marked by the physical properties of the compound. Solubility, degradability, and penetrability into the plants appear to be the major properties of oxamide that determine wheat and soybean responses to the compound.

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Oxamide, a slow-release N source, may have anti-ethylene growth regulator effects as well as nutritional effects on plants. Responses of wheat (*Triticum aestivum* L.) to foliar applications of oxamide and other N sources, of soybean (*Glycine max* L. Merr.) to foliar and soil applications of oxamide, and of both species to oxamide in hydroponic solutions were measured to assess growth regulator and nutritional effects. Wheat studies were at two locations for two years and soybean studies were at one location for one year. Foliar applications of oxamide to wheat increased grain protein concentration in three of four tests but were less effective than urea foliar applications. Oxamide supplied as foliar or soil treatment to soybean increased the test weight but had little other discernible effect. In hydroponic cultures, oxamide was inferior to nitrate as an N source. We concluded that oxamide did not function as a growth regulator and that plant responses were determined by solubility, degradability, and penetrability of the compound.